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MONTANA STATE HIGHWAY DEPARTMENT

HIGHWAY PLANNING SURVEY

IN COOPERATION WITH

PUBLIC ROADS ADMINISTRATION

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DESCRIPTION OF
DEFICIENCY AND CONSTRUCTION PRIORITY FORMULA

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Submitted October, 1948

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Helena, Montana
October 18, 1948

DESCRIPTION OF
DEFICIENCY AND CONSTRUCTION PRIORITY FORMULA

In 1943 and the early part of 1944 State and Public Roads Highway Planning Survey personnel devoted a great deal of time and study to the development of a formula which would show the deficiency of a highway in percent as well as the construction priority of any particular section. A formula was finally developed which we believe approximately accomplishes these purposes. The formula has been given extensive study and has been used in practice for several years and minor revisions and improvements have been made from time to time.

The following explanation covers the formula as now in use.

Priority rating $= (ADT)^{3/5} (A + B + C + 3D + 3E + F)\ 1/10$

% of deficiency $= (A + B + C + 3D + 3E + F)\ 1/10$

Maximum % of deficiency = 100%

All calculations are on a percentage basis showing percent of deficiency.

A = % Grade deficiency

B = % Alignment deficiency

C = % Sight Distance deficiency (vertical and horizontal)

D = % Surface deficiency (width and thickness)

E = % Base deficiency (width and thickness)

F = % Roadbed width deficiency

ADT = 125% of the 1947 average daily traffic which is the estimated ADT for 1965.

EXAMPLES

A - Length substandard grades = 2112'

Length of section - 4 mi. = 21120'

2112/21120 = .10 or 10% - If no road exists, use 100%

B - Length substandard curvature = 4500'

Length of section = 4 mi. = 21120'

4500/21120 = .21 or 21%

If no road exists, use 100%

C - Arbitrarily allow 5% for each substandard sight distance per mile.

No. of substandard vertical sight distances in section, 12

No. of substandard horizontal sight distances in section, 8

Length of section = 4 miles

20/4 = 5 = average No. per mile = 25%

If no road exists, use 100%

D - Existing Surface = 1" x 16' = 16, needed 3" x 22' = 66

Deficiency = 50/66 = .76 or 76%

If no surface exists, or if no road exists, use 100%

E - Existing base = 3" - Total required 8"

Deficiency = 5" = 63%

If no base exists or if no road exists, use 100%

F - Existing width = 16' - Required width 40'

Deficiency = 24' = 60%

If no road exists, use 100%

Priority factor = $(ADT)^{3/5}$ (10 + 21 + 25 + 3 x 76 + 3 x 63 + 60) 1/10 =

$(ADT)^{3/5}$ x 53.3   53.3% = Weighted deficiency of road

To facilitate coding and machine operations the following formula is used:

$$F = (1.25V)^{3/5} \left(\frac{G}{L_1} + \frac{D_1}{L_1} + \frac{.05(D + C)}{L} + 3\frac{(WT - W_1T_1)}{WT} + 3\frac{(B-B_1)}{B} + \frac{R-R_1}{R} \right)^{1/10}$$

Where

F = Priority rating factor.

V = Average annual 24-hr. traffic for 1947.

G = Total length of excessive grades in feet.

L_1 = Total length of road under consideration in feet.

Factor $\frac{G}{L_1}$ When G is zero leave the factor out, and when no grading has been done Code 1.00 or 100%.

D_1 = Total length of deficient horizontal curves in feet.

Factor $\frac{D_1}{L_1}$ When D_1 is zero leave the factor out, and when no grading has been done, code 1.00 or 100%.

D = Total number of deficient horizontal curves.

C = Total number of deficient vertical curves.

L = Total length of road under consideration in miles to the nearest thousandth. Example: 4.176 miles

Factor $\frac{.05\ (D + C)}{L}$ When (D + C) equals zero leave the factor out and when no grading has been done, code 1.00 or 100%. Note: Each deficient curve per mile is given a value of 5%. The total value of this factor is never to exceed 1.00 or 100%

W = Required width of surfacing to the nearest foot.

W_1 = Present width of surfacing to the nearest foot.

T = Required thickness of surfacing in inches to the nearest tenth.

T_1 = Present thickness of surfacing in inches to the nearest tenth.

Factor $3\left(\frac{WT - W_1T_1}{WT}\right)$ When ($WT - W_1T_1$) equals zero, leave the factor out. This factor represents the surfacing on the road and is multiplied by 3 to give it more weight. We have found in the study of the formula and the computing of priority ratings on thousands of sections of road that surfacing and base have more to do with the necessity and demand for reconstruction and improvement than any other defect in the road. The maintenance department has more complaints when the surface is in poor condition than when the road is narrow, crooked or steep grades exist.

B = Required thickness of base in inches to the nearest tenth.

B_1 = Present thickness of base in inches to the nearest tenth.

Factor $3\left(\frac{B-B_1}{B}\right)$ When $(B-B_1)$ is zero, leave the factor out. This factor, which represents the base, was also multiplied by 3 to give it more weight.

R = Required width of roadbed at grade to the nearest foot.

R_1 = Present width of roadbed at grade to the nearest foot.

Factor $\frac{R-R_1}{R}$ When $(R-R_1)$ equals zero, leave the factor out.

The formula might be written as follows:-

Factor = Traffic (Grade + Alignment + Sight Distance + Surfacing + Foundation + Roadbed in Percent) 1/10

A brief description of the factors follows:

"V", the traffic factor, is based upon 1947 traffic multiplied by 125% to represent estimated traffic for 1965 and the volume that should be used for design purposes. This assumes that the traffic will increase at about the same ratio that it did before 1947. This will probably not be true but we can adjust the factor each year when we make up new tables. The minimum traffic used for any road is 100.

It was necessary to make up the formula using annual average 24-hour traffic as all Montana data and traffic flow maps are compiled upon this basis. Studying the records from the automatic counters it was found that the thirtieth maximum traffic hour of 20 represented an annual average 24-hour traffic of about 200. Forty represented about 400, etc. This is not absolutely true but the variation is so small that it does not materially affect the results obtained from the formula.

We applied this formula to all primary roads in the State and found that a road with an estimated 100 vehicles per day and an 85% deficiency had such a small priority factor that it would never be improved when compared with a road

that had 3,500 vehicles per day and 10% deficiency. We therefore introduced another factor into the formula by taking the 3/5 power of the traffic. This gives more weight to the traffic on small traffic roads and less weight to the traffic on large traffic roads, and in the case of the above example makes the two roads have about equal priority. Applying this formula to all primary roads in the State seems to give a more equitable priority number to all roads. The 3/5 power of the traffic seems to fit the conditions in Montana but other states can change this to meet their requirements, or eliminate it altogether.

$\frac{G}{L_1}$	is the grade deficiency factor and the numerator is the sum of all grades that exceed the design standard. Each grade is computed separately, taking the distance between tangent intersections and subtracting one-quarter of the length of each vertical curve.
$\frac{D_1}{L_1}$	is the alignment factor and the numerator is the sum of the lengths of all curves that exceed the design standard taken from P.C. to P.T.
$\frac{.05\,(D + C)}{L}$	is the sight distance factor and the numerator is the sum of all convex vertical curves that are less than the design standard plus the sum of all horizontal curves that are greater than the design standard. Each curve being counted as one with a maximum of 20 per mile.
$\frac{(WT - W_1T_1)}{WT}$	is the surfacing factor and is the ratio of deficiency that the present surface has to the required design.
$\frac{B - B_1}{B}$	is the foundation factor and is the ratio of deficiency that the present base has to the required base.
$\frac{R - R_1}{R}$	is the roadbed factor and is the ratio of deficiency that the present width of roadbed bears to the required width.

Before any computations are made we rate each piece of road "good", "fair", "poor", or "worn out", according to the present condition of the surfacing and base. This rating is based upon the last report of the Public Roads maintenance engineer after he has made his maintenance inspection. We feel that in this way we get away from any personal classification that might be made by a State Highway employee and get as unbiased an opinion as possible. Where a road is classified as "good" we give full value to the present surfacing and base. Where the road is classified as "fair" we give 2/3 value. Where it is classified as "poor" we give 1/3 value, and where it is classified as "worn out" we give zero value. For instance, where the section in question has 3" top and 6" base and is classified as "poor" we use 1" for top and 2" for base in the formula. Roads that were not constructed by the State or Public Roads Administration are given credit in the same way for the surfacing and base now on the road. In this way we feel that we have taken care of the obsolescence due to traffic wearing out the surface and destroying the base. We believe that the computed deficiency rating is as near a true arithmetic determination as it is possible to obtain.

The entire State was carefully studied before assigning the 40-mile design speed category to a section of road, and as a result we have only 167.8 miles of road in the entire State designed for a 40-mile speed. These sections are all in the mountains where cost would be prohibitive to design for a 60-mile speed.

In working up the formula, maintenance costs were considered as one factor but this was eliminated later since we could not assign a definite maintenance cost to any short section of road. The political question also entered maintenance figures, which complicated the determination of the actual maintenance costs. We still believe that maintenance costs, if reliable figures were available, should be one factor in the formula.

All the data given on the computation sheets are now punched on alphabetical and numerical cards; we can then tabulate the information as desired. The tables now being used list the value of each of the six deficiency factors for each section of road, so that one can see at a glance just what item or items on each project are deficient, and to what extent. Without any additional work, tables can be prepared in any order desired, by project number, by deficiency, by priority number, by route, etc.

When tabulations are prepared in order of priority or deficiencies they are marked off into groups by red lines to facilitate locating or reporting the standing of any project. For instance, priority tabulations for 1948 were broken into four equal categories on a mileage basis. Deficiency tabulations were broken into six categories, but on a percentage basis as that is the only method that can be used to reflect the actual condition or deficiency standing of a group. Equivalent Deficient Mileage or Deficient Mileage as shown in the tabulation represents the length of a project multiplied by its percent of deficiency. Both priorities and deficiencies can be plotted in colors on state maps thus reflecting at a glance the overall condition of the system but due to the large amount of work involved this has not been done recently.

Practically all Highway Engineers charged with the responsibility of the administration of the State Highway System and selection of projects needing improvement, have stated that it is surprising how closely the formula reflects actual conditions on the ground. However, it should be emphasized that the formula is only intended to be used as an aid and a check in selecting projects for programming as in the final analysis dependence must be placed on field inspections and engineering judgement.

It is probable that the formula can be further improved by future application but to date it has been of great value to the State in allocating funds to the twelve financial districts according to the State law. It is also proving of value in showing how traffic will affect the design and standards applicable to different sections of road.

In working up the formula we took into consideration the cost of constructing or reconstructing each section of road, but we finally eliminated this factor from the formula as we believe that these costs are neither a measure of deficiency nor a measure of the need for improvement. We are convinced that it is impracticable to include construction costs in the formula due to several very obvious reasons, such as traffic hazards that should be eliminated regardless of cost, and exceptionally high cost bottlenecks in the middle of long sections already improved, etc. Projects of this kind may never reach the top of a priority list as many other projects may have higher traffic and lower costs.

However, after a priority list has been established it becomes an engineering and administrative problem to determine which of those projects at the top of the list should be constructed first.

Costs, will, of course, have to be taken into consideration in determining the overall financial requirements of the State. But, above all, the most valuable information shown by the formula is the existing deficiency of every project on the F.A. System.

The standards adopted for comparing each section of road were those approved by the American Society of State Highway Officials, or better. While they have set up 30, 40, 50, 60 and 70 miles per hour speed classifications we have used only the 40 and 60 miles per hour speeds as applied to mixed traffic. The variations in design for the different speeds and kind of traffic were so minor that we did not feel justified in setting up

other speed categories. All Montana traffic can be classified as mixed.

One of the principal advantages of the formula is that it eliminates the personal equation in setting up construction programs as the factors used are strictly mathematical and are based entirely on the current physical condition of the road. The only place in the formula where the personal equation might enter is in determining the present condition of the surfacing and foundation. However, as stated previously we eliminated all State prejudice by basing this factor upon the maintenance reports made by the Public Roads representative on his biennial maintenance inspections.

The formula is being used in three practical ways:

1. To determine deficiency of the Federal Aid system in total and by sections.
2. In making up all construction programs a list of projects is submitted by the Maintenance Department, one by the Bridge Department, and one by the Planning Survey, the latter being based upon the priority ratings. These are carefully gone over by a committee consisting of the Chief Engineer, the Bridge Engineer, the Maintenance Engineer, the Planning Survey Director, and the Secretary of the Highway Commission and a program set up. After all factors have been given due consideration it is required that all projects be selected from the first priority group unless extraordinary reasons can be advanced justifying selection of certain projects with lower priority.
3. The State law requires that the amount of funds used for construction shall be distributed to each financial district on the ratio of the uncompleted mileage in each financial district to the total uncompleted mileage in the State, and this ratio is determined entirely by use of the deficiency and priority formula.

Tables of design and sight distance data are attached together with a copy of the code and computation sheet now being used in practice.

Montana State Highway Department
Traffic and Planning Section
Public Roads Administration

Basic Design Categories
Table 1

					Sight Distance								
					Non-Passing			Passing					
Standard	Average Daily Traffic	Classification	Max. Grade %	Max. Curvature (Degree)	Horiz. Curvature (Degree)	Vertical Curvature (Algebraic Difference)	Feet	Feet	Shoulder Width (Ft.)	Width of Road Bed at Grade (Ft.)	Width of Surfacing (Ft.)	Minimum Type of Surfacing	Minimum Base Course (Inches
0	0- 400	50 M 40*	7	14	14	SEE TABLE NO. 2	290	800	2'	28'	24'	$2\frac{1}{2}$" Oil	8"
1	401- 800	100 M 40	7	14	14		310	1100	3'	30'	24'	$2\frac{1}{2}$" Oil	8"
2	801-2000	200 M 40	7	14	14		320	1100	4'	32'	24'	$2\frac{1}{2}$" Oil	8"
3	2001-3500	300 M 40	7	14	14		330	1100	6'	36'	24'	$2\frac{1}{2}$" Oil	8"
4	0- 400	50 M 60	6	6	6		460	1700	2'	28'	24'	$2\frac{1}{2}$" Oil	8"
5	401- 800	100 M 60	6	6	6		470	2100	3'	30'	24'	$2\frac{1}{2}$" Oil	8"
6	801-2000	200 M 60	6	6	6		480	2100	4'	32'	24'	$2\frac{1}{2}$" Oil	8"
7	2001-3500	300 M 60	6	6	6		500	2100	6'	36'	24'	$2\frac{1}{2}$" Oil	8"
Interstate System													
8	0-2000		6	6	6		480	2100	4'	32'	24'	$2\frac{1}{2}$" Oil	8"
9	2001 -over		6	6	6		500	2100	8'	40'	24'	$2\frac{1}{2}$" Oil	8"

Note: Roads having over 3500 vehicles per day require special design.

* = 50 mixed vehicles at 40 miles per hour

TABLE NO. 2

Table giving length of vertical curve required for various
Non - passing sight distances

December 18, 1943

Algebraic Difference between grades for convex curvature.	Length of vertical curve for a Non-passing sight distance of: 280 feet	Length of vertical curve for a Non-passing sight distance of: 290 feet	Length of vertical curve for a Non-passing sight distance of: 310 feet	Length of vertical curve for a Non-passing sight distance of: 320 feet	Length of vertical curve for a Non-passing sight distance of: 330 feet	Length of vertical curve for a Non-passing sight distance of: 460 feet	Length of vertical curve for a Non-passing sight distance of: 470 feet	Length of vertical curve for a Non-passing sight distance of: 480 feet	Length of vertical curve for a Non-passing sight distance of: 500 feet
1.00	96	103	117	125	133	258	269	281	305
2.00	191	205	234	250	266	516	539	562	610
3.00	287	308	352	375	398	774	808	843	915
4.00	382	410	469	500	531	1032	1078	1124	1220
5.00	478	513	586	624	664	1290	1347	1405	1524
6.00	574	615	703	749	797	1548	1616	1686	1829
7.00	669	718	820	874	930	1806	1886	1967	2134
8.00	765	820	938	999	1062	2064	2155	2248	2439
9.00	860	923	1055	1124	1195	2322	2425	2529	2744
10.00	956	1026	1172	1249	1328	2581	2694	2810	3049
11.00	1052	1128	1289	1374	1461	2839	2963	3091	3354
12.00	1147	1231	1406	1499	1594	3097	3233	3372	3659
13.00	1243	1333	1524	1623	1726	3355	3502	3653	3963
14.00	1339	1436	1641	1748	1859	3613	3771	3934	4268

MONTANA HIGHWAY PLANNING SURVEY

CODING AND COMPUTATION SHEET FOR PRIORITY RATING

F.A. ROUTE NO. 2

DATE 8-15-48 SHEET 2 OF 27

COUNTY NAME	COUNTY NUMBER	FINANCIAL DISTRICT	FEDERAL AID ROUTE NO.	PROJECT NUMBER	PROJ. LETTER	SECTION NO.	NO. OF SECTS.	SECTION LENGTH	ACCUMULATED MILEAGE	1947 TRAFFIC	3/5 POWER	1965 TRAFF.	PERCENT DEFICIENT	PRIORITY RATING	CLASSIF.	SYSTEM	DEFICIENT MILEAGE	G / L1	D1 / L1	.05(D+C) / L	3 ((WT − W1T1) / WT)	3 ((B−B1) / B)	(R − R1) / R	
Mineral	31	8	2	8	K	1	1	7620	349	766	614	958	511	3138		1	3.894	0 = 000	6670 / 40234 = 016	.05(2+4) / 7.620 = 010	(24x2.5 − (18x0.8)) / 24x2.5 x 3 = 228	8−1.8 / 8 x3 = 232	32−24 / 32 = 025	P
Mineral	31	8	2	8	N	1	1	333	352	766	614	958	252	1547		1	.084	0 = 000	0 = 000	.05(0+0) = 000	(24x2.5) − (24x1.7) / 24x2.5 x 3 = 096	8−4 / 8 x3 = 150	32−30 / 32 = 006	F
Mineral	31	8	2	8	O	1	1	235	354	766	614	958	273	1676		1	.064	0 = 000	0 = 000	.05(0+1) / 0.235 = 021	(24x2.5) − (24x1.7) / 24x2.5 x 3 = 096	8−4 / 8 x3 = 150	32−30 / 32 = 006	F
Mineral	31	8	2	183	E	1	1	7229	427	766	614	958	10	61		1	.072	1450 / 38169 = 004	740 / 38169 = 002	.05(1+5) / 7.229 = 004	(24x2.5) − (24x2.5) / 24x2.5 x 3 = 000	8−10 / 8 x3 = 000	32−32 / 32 = 000	G
Mineral	31	8	2	254	A	1	2	3033	457	766	614	958	3	18		1	.009	0 = 000	0 = 000	.05(0+2) / 3.033 = 003	(24x2.5) − (24x2.5) / 24x2.5 x 3 = 000	8−10 / 8 x3 = 000	32−32 / 32 = 000	G
Mineral	31	8	2	254	A	2	2	885	466	766	614	958	316	1940		1	.280	0 = 000	450 / 4672 = 010	.05(2+4) / .885 = 034	(24x2.5) − (22x1.5) / 24x2.5 x 3 = 135	8−5 x3 = 112	32−24 / 32 = 025	G
Mineral	31	8	2	254	C	1	2	1997	486	766	614	958	410	2517		1	.819	0 = 000	450 / 10544 = 004	.05(1+5) / 1.997 = 015	(24x2.5) − (22x1.0) / 24x2.5 x 3 = 190	8−3.3 x3 = 176	32−24 / 32 = 025	F
Mineral	31	8	2	254	C	2	2	4120	527	814	636	1018	425	2703		1	1.751	1900 / 21754 = 009	1550 / 21754 = 007	.05(4+11) / 4.120 = 018	(24x2.5) − (22x1.0) / 24x2.5 x 3 = 190	8−3.3 / 8 x3 = 176	32−24 / 32 = 025	F
Mineral	31	8	2	254	B	1	2	2207	549	814	636	1018	396	2519		1	.874	0 = 000	0 = 000	.05(0+2) / 2.207 = 005	(24x2.5) − (22x1.0) / 24x2.5 x 3 = 190	8−3.3 x3 = 176	32−24 / 32 = 025	F
Mineral	31	8	2	254	B	2	2	5414	603	814	636	1018	334	2124		1	1.808	0 = 000	600 / 28588 = 002	.05(2+7) / 5.414 = 018	(24x2.5) − (22x1.7) / 24x2.5 x 3 = 113	8−3.3 x3 = 176	32−24 / 32 = 025	F
Mineral	31	8	2	271	C	1	1	319	606	814	636	1018	422	2684		1	.135	0 = 000	700 / 1684 = 042	.05(1+1) / .319 = 031	(24x2.5) − (24x0.8) / 24x2.5 x 3 = 204	8−4.3 x3 = 139	32−30 / 32 = 006	P
Mineral	31	8	2	8	C	1	2	1097	617	814	636	1018	567	3606		1	.622	0 = 000	0 = 000	.05(0+1) / 1.097 = 005	(24x2.5) − 16x0.2) / 24x2.5 x 3 = 284	8−1.5 x3 = 244	32−21 / 32 = 034	P